SECTION IV
ASSESSMENT OF NON-SPECIFIC AIR POLLUTION DAMAGES

OVERVIEW OF THE PROBLEM

Attempts have been-made to assess the effects of air pollution on human health, materials, vegetation, aesthetics, soiling, animals and the natural environment. Studies focusing on specific effects have typically used the technical coefficients of production and consumption approach. These studies will be reviewed in later sections. It is somewhat more difficult to identify what effects are measured when the investigator undertakes market studies or opinion surveys to investigate the behaviour or awareness of air pollution sufferers.

In those cases where it is not clear what effects are being evaluated, the term "non-specific" will be used. Studies that have evaluated these non-specific damages of air pollution, will be reviewed in this Section. Such a review will afford the opportunity to assess critically the merits of each study which , in turn, will provide a basis for the extrapolation of findings to develop a national estimate of the cost of air pollution damage. This chapter will review then: (1) opinion surveys with air pollution sufferers; and (2) market studies that have employed the property value method to measure air pollution losses.

OPINION SURVEYS

Some of the earliest research to assess public awareness and concern about air pollution was done by deGroot and others (1966) in Buffalo. Their findings supported the hypothesis that there was direct relationship between the perception of the seriousness of air pollution and actual ambient air quality in the area. With respect to the perception of effects of air pollution, the study showed that: (1) the majority of people believed that air pollution is detrimental to human health; (2) three-fourths of the people queried in 1959 thought that air pollution had a bad effect on real estate; and, (3) residents perceived air pollution as bad elsewhere, but not in their own neighborhood.

Another study was performed in Clarkston, Washington, by Medalia and Ffnkner (1965) on the impact of odors and smoke emanating from a local pulp mill. Of approximately 100 interviews, 91% perceived air pollution in the communitv as an odor problem, 74% as a visibility problem, and 62% claimed it to be a problem in nose-throat irritation. Concern with air pollution was found to be unrelated to location of respondents' residence with respect to the pollution source. This absence of a relationship was probably due to the pervasive nature of the pollution. Concern with air pollution was found to vary directly with social status and with attitudes about civic pride, desire to eliminate the problem, length of residence, and occupation prestige of the household head.

A broader study by Williams and Edmisten (1965) in Nashville, Tennessee. included an examination of individual perceptions of pollution. People in 3,032 dwelling units were interviewed to test the hypothesis that perception and concern for air pollution would be directly related-to neighborhood pollution levels. Their findings supported the hypothesis. Furthermore, the higher the socioeconomic status, the greater was the correlation between degree of concern and air pollution levels. 'They also found that the citizens' perception of air pollution was influenced more by the frequency of high daily levels of pollution than by high monthly. seasonal, or average levels.

A recent perception and attftudnal survey was reported on by Mason (1972). His research proceeded in two steps. First, a test was made of the hypothesis which stated'that perceived changes in air quality in a community are defined or redefined, in part, by the local mass media and that such a definition is sufficient to form attitudes towards the topic. An emprical test of the hypothesis involved a content analysis of dafly newspapers in two communities where visible changes in air quality levels were known to occur. The study took place in two cities in the Willamette Valley--Salem and Eugene, Oregon--and the pollution studied was the visibility-restricting smoke generated by the annual burning of grass stubble. Measurement of attitudes of a random sample of adults in these communities was also completed twice--once when vfsibility was low and once when it was normally hiqh.

Results showed that: (1) attitudes were likely to have been formed by, and are subject to change as a result of, mass media definition; and (2) attitudes did not change as a result of known changes in air quality.

In the second step of Mason's study, a theoretical model was tested concerning the communication of air quality information to the public.[49] Interview data, gathered in the same manner as before, were analyzed by two-stage least squares. The accuracy of a respondent's perception of visibility was also determined. The results suggested that different communications models represented different stages of the same underlying communication process. Mason concluded that an understanding by public relations personnel in environmental programs of the complex communication process should enhance their efforts to speed up the formation of positive attitudes and the level of knowledge of people on the topic of environmental pollution.[50]

Once information has been gathered on people's perception and attitude concerning environmental pollution or the effects of that pollution, the next step is to value the individual's willingness to pay to reduce either the pollution or the risk of his experiencing certain effects.

Ridker[51] surveyed the residents near a steam plant to determine the cost of cleaning up after a malfunction in the boilers caused a fumigation of the neighborhood of 3,500 residential units with unusually high amounts of soot. The 1965 survey not only measured costs of cleaning, but also attempted to measure psychic costs by asking "willingness-to-pay" questions. The responses of 10 individuals who provided answers for measured and willingness-to-pay costs are shown in Table 1. Psychic costs are considered to be aesthetic costs or losses greater than the direct, measured costs that people suffer, and are valued at what these sufferers are willing to pay to avoid them.

Table 1. COST OF CLEANING UP AFTER BOILER MALFUNCTION

Respondent	Measured costs, $	Willingness-to-pay costs, $	Psychic costs, $
1	9.45	10.00	0.55
2	43.75	50.00	6.52
3	45.61	45.61	0.00
4	19.78	25.00	5.22
5	15.67	25.00	9.33
6	25.32	30.00	4.68
7	13.59	25.00	11.41
a	12.95	20.00	7.05
9	4.25	4.25	
10	a.79	a.79	

The results indicate that these heads of households generally were willing to pay at least the measured cost of pollution clean-up to avoid the necessity for clean-up. Usually they were willing to pay more than the measured cost. The results indicate that the residents were willing to pay on the average, 27% above the measured cost of clean-up-in order to avoid the clean-up.

These results must be qualified for several reasons: First, since the survey was constructed in only a few days, one must allow for the probability of an incomplete questionnaire and an unreliable sample. Second, the ten respondents on willingness-to-pay were too few to be representative of the psychic costs of the sample of 122 households.

Another survey on willingness-to-pay for an improvement in air quality was conducted by Lawyer (1966) among 362 of the 6,424 families in Morgantown, West Virginia. Table 2 shows the percentage of respondents by the amount each would pay each year "... if all air pollution were reduced below the point where it was noticeable (or harmful)."[52]

Table 2. AMOUNT OF MONEY RESPONDENTS WOULD PAY ANNUALLY TO REDUCE AIR POLLUTION IN MORGANTOWN, WEST VIRGINIA*

Amount, $	Respondents, %
Zero or no response	38.4
1 to 5	23.9
6 to 10	9.4
11 to 15	2.5
16 to 20	4.7
21 to 25	6.3
26 to 30	0.3
31 to 35	0.6
36 to 40	0.3
40	13.5
Total	99.9[a]

[a] Error resulted from rounding of figures

* Source: Robert E. Lawyer. An Air Pollution Public Opinion Survey for the City of Morgantown, West Virginia. West Virginia University, Morgantown. Unpublished Master's Thesis. 1966.

The average amount respondents would be willing to pay can be calculated to be $16.46. The "Zero or no response" category is not considered in the averaqe because it is probable that many of the observations in this class are non respondents. The averaqe of the $1 to $5 class is taken to be $3.50 since it is assumed the class really extends to $5.00. The averages of each subsequent class are $5.00 higher than the previous one. The highest class is assumed to have an average mark of $40.

An averaqe payment of $16.46 per year per respondent is much higher than the willingness-to-pay results' of a study by Williams and Bunyard (1966).

They reported that 66% of those interviewed in a 1963 survey of the St. Louis area were willing to pay $5.00 per year in higher living costs for clean air and that 85% of those interviewed would pay $1.00 per year in higher taxes.

This brief literture survey has been a review of a rapidly growing body of knowledge concerning the perception or awareness of and the formation of attitudes about air pollution, and the willingness to pay for reductions of the perceived effects of air pollution.

PROPERTY VALUE STUDIES

Another method that has been used to measure willingness-to-pay is a particular type of market study--the property value approach (For detailed discussion of the methodology, see Section III). As with the opinion surveys reviewed earlier in this section, the property value method measures "non-specific" effects. By applying classical least-squared regression procedures, the existence of a statistically significant relationhip between air pollution and property values can be tested.

Ridker and Henning - St. Louis

The first serious use of the property value or housing market estimator was made by Ridker and Henning (1967). They used the statistical technique of multiple regression analysis to isolate the significance of air pollution--sulfation, in this case--in explaining changes in property values. Using 1960 census data and pollution readings from the 1963-64 Interstate Air Pollution Study, their regression equation explained over 90% of the variation in the median property values of the St. Louis Standard Metropolitan Statistical Area (SMSA) census tracts. The variables in their regressions were as follows:

MPV = Median property value
SUL = Annual geometric mean sulfation levels
MNR = Median number of rooms

PBR = Percentage homes recently built

HPM = Houses per mile

TIZ = Bus travel time to St. Louis central business district

HWA = Accessibility to highways

SCHI = School quality

OCR = Occupation ratio (ratio of craftsmen, foremen, operatives and laborers to total work force)

PPU = Population density

PNW = Percentage non-white residents

RILL = Dummy variable indicating whether census tract in Illinois or Missouri, orthogonal to sulfation

RMFI = Median family income, orthogonal to MNR, HPM, OCR

They concluded that the partial regression coefficients for sulfation can be interpreted as meaning that if the average sulfation levels to which any single family dwelling unit is exposed were to drop by 0.25 mg of SO_3/100 cm^2/day, the value of that property can be expected to rise by at least \$83 and more likely closer to \$245. The coefficient of SUL, then, estimates the minimum sum needed to induce receptors to endure various levels of whatever pollution a sulfation index measures if all other factors have their mean values. At any inducement less than this, receptors on the average would find it to their benefit to demand either a higher payment (which in essence becomes a cost of production to the emitter to use the atmosphere for waste disposal) or a cleaner environment.

Eerbe - Toronto

Zerbe (1969) used a theoretic rationale similar to Ridker and Henning in estimating the air pollution damage to residential property in Toronto and Hamilton, Ontario, Canada. He related property values for each census tract to: four variables representing neighborhood characteristics; five variables representing property characteristics; and, two varfables representing average levels of sulfur dioxide and dustfall pollution. On the basis of his best fitting equation, which explained almost 96% of the variation in median property values, Zerbe concluded that for Toronto, other things being equal, for each increase in 1 mg SO_3/day. property values will fall by an amount between \$800 and \$1800 for each single family dwelling. His best estimate was that values will fall by about \$966.[53]

Jaksch and Stoevener - Toledo, Oregon

In like manner, Jaksch and Stoevener (1970) conducted a study in Toledo, Oregon, using dustfall measurements as the pollutant variable. Their hypothesis was that air pollution represents an economic cost to the affected community and that such cost is reflected in the property values. They found that reductions in property values due to increasing air pollution levels are likely to be greater for higher-valued, more-developed properties than for less-developed, lower-valued properties. Two models were developed to analyze the relationship between dustfall pollution and residential prooerty values, the difference being the measure of the price of residential property. In one, it was found that an increase of 1 ton/ml^2-month in dustfall caused property values to decline by $277 per acre. In the other, it was found that a similar increase in dustfall caused a decline in prooerty values of $29 per market transaction.

Anderson and Crocker - St. Louis, Kansas City, Washington, D.C.

Anderson and Crocker (1970) gave more attention to the specification of their housing market model and to the formulation of the theoretic rationale underlying their study, and thus, significantly refined the method first employed by Ridker and Henning. Anderson and Crocker studied the covariation of sulfation, suspended particulates, and census tract median property values in St. Louis, Washington, D.C., and Kansas City. The equations most successful in explaining the variation in prooerty values in each of the three cities are listed in Table 3.

A multiplicative (linear in logs) equation form gave the best statistical fit--highest R^2--in the regression for each city. Without exception, the signs of the coefficients for all explanatory variables, including the air pollution variables, were in agreement with _a priori_ expectations. The hypothesis that air pollution (as Anderson and Crocker defined it) and property values are inversely related, was confirmed.

Table 3. ANDERSON-CROCKER PROPERTY VALUE REGRESSION EQUATIONS

City	Equation	$(R^2)^a$	Degrees[b] of Freedom
St. Louis	$\ln MPV = \underset{(.6332)^c}{3.5407} - \underset{(.0340)}{.1019} \ln (PSN) - \underset{(.0475)}{.1192} \ln (PPT) + \underset{(.0772)}{.7660} \ln (MFI)$ $- \underset{(.0087)}{.0802} \ln (DLP) - \underset{(.0162)}{.0257} \ln (OLD) + \underset{(.0060)}{.0373} \ln (NWT) - \underset{(.0382)}{.1387} \ln (DIS)$	.7550	228
Kansas City	$\ln GPV = \underset{(.7261)}{3.5775} - \underset{(.0396)}{.0782} \ln (PSN) - \underset{(.0362)}{.0876} \ln (PPT) + \underset{(.0898)}{.6720} \ln (MFI)$ $- \underset{(.0094)}{.0405} \ln (DLP) - \underset{(.0124)}{.0721} \ln (OLD) - \underset{(.0067)}{.0058} \ln (NWT) - \underset{(.0245)}{.0623} \ln (DIS)$	.8231	179
Washington,D.C.	$\ln MPV = \underset{(.4012)}{3.3901} - \underset{(.022)}{.0712} \ln (PSN) - \underset{(.0318)}{.0610} \ln (PPT) + \underset{(.0447)}{.7677} \ln (MFI)$ $+ \underset{(.0059)}{.0044} \ln (DLP) - \underset{(.0103)}{.0106} \ln (OLD) + \underset{(.0064)}{.0251} \ln (NWT) - \underset{(.0158)}{.0582} \ln (DIS)$	.6966	267

Where:
- MPV = Median property value
- PSN = Annual arithmetic mean sulfation
- PPT = Annual arithmetic mean suspended particulates
- MFI = Median family income
- DLP = Percentage homes dilapidated
- OLD = Percentage homes more than 20 years old in 1959
- NWT = Percentage of homes occupied by nonwhites
- DIS = Distance to central city

Notes: [a]Shows what part of the variation in property values across census tracts within the SMSA is explained by the equation.

[b]The degrees of freedom relate to the level of confidence one can have in the stability of the R^2.

[c]The figures in parentheses are the standard errors of the coefficients.

From their equations, Anderson and Crocker concluded that the pollution (sulfation and suspended partfculates combined) elasticity of MPV falls between -0.1 and -0.2. Thus for every change of 0.1 mg SO_3/100 cm^2-day in sulfation plus 10 ug/m^3-day of suspended particulates over a given census tract, the best estimate of the change in that tract's MPV lies in the interval $300 to $700.

Crocker - Chicago

Crocker (1971) in an attempt to extend further and to test the methodology formulated by himself and Anderson, performed a study in Chicago. The purposes of this study were: (1) to test new economic hypotheses about the relation between property values and air pollution; and (2) to remove possible sources of statistical bias present in previous studies. In studying the covariation between air pollution dosages (sulfur dioxide and suspended particulates) and property values (using FHA and census tract data) his results were consistent with those from other property value studies.

On the average, the sum of the damage elasticities for sulfur dioxide and suspended particulates in the City of Chicago were found to be between -.30 and -.40. This would mean that the average marginal capitalized damages are about $450 for: (1) an additional 10 ug/m^3/day of suspended particulates; plus, (2) an additional part per billion by volume per day of sulfur dioxide.

Peckham - Philadelphia

Peckham (1970) studied the covariation of urban property values and air pollution to determine if the relationship determined in other studies, would hold in Philadelphia. Peckham concluded, "It does appear clear that negative and, in most cases, unambiguously significant coefficients have been found for both pollution variables, and that in confirmation of Cracker and Anderson, the elasticity of MPV with respect to both AMS (annual arithmetic mean sulfation) and SPT (annual arithmetic mean suspended particulates) is about -.2."[54] Peckham's estimates of the marginal capitalized sulfation damage of .1 mg SO_3/100 cm^2-day were (for two equations) $600 and $750.

Spore - Pittsburgh

Spore (1972) performed a cross-section analysis of the relationship between air pollution and property values in Pittsburgh. The pollutant measurements of dustfall and sulfur dioxide (as determined from sulfation data) were regressed against 1970 U.S. Bureau of the Census data. By applying classical least-squares regression procedures (multiplicative equations), the presence of a statistically significant inverse relationship between air pollution and property values was shown, confirming the conclusions of earlier studies. His analysis showed that for an average property, the effects associated with an additional 5 tons/mi^2-month of dustfall plus an additional .005 ppm/day SO_2 (or, a 10-15% increase in air pollution dosages) result in an increase in pollution damage costs of approximately $150-$200.

Weiand - St. Louis

Weiand (1970) attempted to test the hypothesis that air pollution is negatively related to property values in St. Louis. His work differed from that of Anderson and Crocker and Ridker and Henning in that he started from rather different premises. Weiand used a measure of residential acreage to derive a measure of land use intensity as the dependent variable representing the price of housing. Thus, he defined, a commodity of "housing services" as being representative of two variables, the price and the quantity of housing. He then demonstrated that housing services and property values do not vary with one another. With his definition of the commodity of housing services, he studied the effect of air pollution on that variable, but found no statistically significant relationship. Anderson and Crocker argue that there is nothing logically wrong with Weiand's method, but it-is-fraught with more statistical. problems and thus , it is much harder to identify incremental air pollution effects.[56]

Crocker - Polk County, Florida

Crocker's (1968) study in Polk County, Florida shows that the property value method is as applicable to agricultural areas as to urban areas, In fact, Crocker believes that property value estimators used in rural areas may capture a greater proportion of the damages since the health-related costs are likely to be somewhat less important.

In the Florida study Crocker investigated the economic impact of fluoride emissions that emanated from the production of phosphate fertilizers, on surrounding agricultural land. Such land was used either for the production of citrus or for the grazing of cattle. To distinguish between submarkets, separate analyses of the cattle and citrus industries were performed. The most satisfactory estimating equations for citrus was multiplicative while that for grating lands was linear.

The explanatory variables in the citrus equation were statistically significant and possessed a sign in accordance with that expected from economic theory. Over time, the magnitude of the negative coefficient for air pollution consistently followed emission patterns, and in the years 1961 - 1962, the average reduction in sale price for citrus sites in the area was about $150 per acre. By 1964 when fluoride emissions had been significantly reduced, the differential sale prices attributable to the presence of air pollution had disappeared.[57]

Flesh and Weddell - Southern California

Flesh and Weddell (1972) studied the relationship betwen odors and property values in Southern California.[58] Using the same method as that posed by Ridker in his time-series study in St. Louis,[59] Flesh and Weddell attempted to estimate the economic costs of odors through property value differentials. The primary contention was this: if the presence of-odors in an area does have negative impact on home values, the impact should manifest itself in slower growth in home prices, at least at the outset of the problem. They examined growth rates of property values in two "identical-except-for-pollution" residential neighborhoods. The study failed to show significant changes in the differential property values. Either there was no impact of odors on property values or the method of analysis and limits of the data masked the effects.

Summary

In summary, the majority of these property value studies use regression analysis to estimate a partial equilibrium, single-equation model whose explanatory variables include measures of not only air quality, but also location, neighborhood, occupant, and physical property characterstics thought to be determinants of residential property values or rents. With two exceptions,[60] the data measurements were obtained from cross-sectional samples over either individual properties or aggregates of properties, such as census tracts. And with three exceptions,[61] these studies established a statistically significant inverse relationship between air pollution and property values or rents.

Also, most studies have included attempts to uncover the presence of harmful multicollinearity and correct for its effects. Anderson and Crocker found significant collinearity for only the two pollution variables. Thus, they interpret their coefficients as a joint measure or composite of pollution. Both they and Spore agree that, based on their samples, it seems that the ability to uncover the true significance of air pollution as a determinant of property values or rents is not hindered by the presence of multicollinearity between air pollution and other independent variable included in the regression equation.

NATIONAL ESTIMATE OF AESTHETIC AND SOILING COSTS

To estimate total damage costs using the property value technique, one would have to perform separate property value studies for residential, commercial, industrial, and agricultural land. Given the paucity of information in areas other than residential, total damage estimates in this report are only for those damages capitalized in the residential property market and measured through site and improvement differential values.

The findings of the property value studies reviewed here are summarized in Table 4. All studies agree, that air pollution is inversely related to MPV. The magnitude of the marginal capitalized sulfation damage for residential structures for a marginal decrease of 0.1 mg $SO_3/100\ cm^2$-day, lies roughly in -the range \$100 to \$600. This uniformity of results, for six major metropolitan areas, warrants some confidence in the worth of the housing market estimator for estimating national pollution damages.

It is well to recognize the difficulties in the way of making straightforward comparisons of the findings of different regression experiments in different cities. Ridker and Henning, as well as Zerbe use only one on the pollutant

Table 4. SUMMARY OF PROPERTY VALUE STUDIES

Study	City	Pollution Measure	Pollution Coefficient	R^2	Marginal Capitalized Damage
Ridker-Henning	St. Louis	Sulfation[a]			100[b]
Zerbe	Toronto	Sulfation[a]	-.12	.94	97[b]
	Hamilton	Sulfation[a]	-.08	.92	
Anderson-Cracker	St. Louis	Sulfation Suspended particulate	-.10 -.12*	.76	
	Kansas City	Sulfation Suspended particulate	-.08 -. 09*	.82	300-700[c]
	Washington, D.C.	Sulfation Suspended particulate	-.07 -.06**	.70	
Crocker	Chicago	Sulfur dioxide Suspended particulate	.06** -.40	.77	470[d]
Peckham	Philadelphia	Sulfation Suspended particulate	-.10 -.12	.76	600-750[c]
Spore	Pittsburgh	Sulfation Dustfall	+.03* -.12	.81	150-200[e]

*Not significantly different from zero at the .01 level
**Not significantly different from zero at the .05 level

Notes:
[a] Single pollution variable probably measures effect of both sulfaction and suspended particulates
[b] Mean change in MPV per change of .1 mg SO_3/100 cm^2-day
[c] Mean change in HPV per change of .1 mg SO_3/100 cm^2-day plus10 ug/m^3-day change in suspended particulates
[d] Mean change in MPV per change of .001 parts per million/72 hrs. SO_2 plus 10 up/m^3-day change in suspended particulates
[e] Mean change in MPV per change of .005 parts per million/day of SO2 plus a 5 tons/mi^2-month change in dustfall

regressors in their equations, while the others always use both. Anderson and Crocker argue that the identification of the separate influences of the two, highly correlated pollution variables, can best be achieved when both appear as regressors in the same equation. If this argument is true, it is probable that the marginal damages reported by both Ridker and Henning and Zerbe reflect the influence of both. sulfation and particulate variations.[62]

Despite the pitfall that the pollutant measures in the different studies are not homogenous, it.seems safe to say that in comparing the different studies, the slopes of the estimated damage functions differ from city to city. Peckham says that, "... this conclusion is no necessary discredit to the property value technique for measuring pollution damage, for cities do vary in their meteorology and emission density, and one would expect some corresponding variation in their damage functions."[63] Anderson and Crocker concluded that over the ranges of both sulfation and suspended particulates that they observed, marginal capitalized damages and the responsiveness of damages to pollution, appears to decline with increasing arithemetic mean pollutant concentrations.[64] Thus,, total damages seem to increase at a decreasing rate, and the proportionate change in damages, relative to the proportionate change in pollution concentrations appears to decline with increasing arithmetic mean pollution concentrations. This pattern was observed when the results for areas within an individual city were compared, as well as comparison among cities.[65]

Given a marginal capitalized damage coefficient and assuming that sulfation changes are always evenly distributed among census tracts (i.e., a 10% drop in the annual average sulfation rate for a city implies a 10% drop in corresponding rates for each tract), crude estimates of sulfation damage (as captured in property value differentials) can be calculated by the following equation:

DAMAGE = (Marginal capitalized sulfation damage) x (no. of marginal changes needed to reduce arithmetic annual mean sulfation rate for the metropolitan area to desired background) x (no. of housing units).

The damage given by this relation is total capitalized pollution damage, or the decrease in real property wealth caused by whatever pollution is measured by sulfation.

It should be noted that this damage equation uses linear extrapolation and consequently it can give rise to both under and overestimation biases. These biases are demonstrated in Figures 3 and 4.[66] Figure 3 is an example of under-estimation, and Figure 4 is an example of overestimation. In both figures it is assumed that the slope (b) at the indicated point is at the relevant pollution coefficient taken from a property value regression and that air quality level Q* is "clean air". The solid lines are the "true" property value-pollution functions. The dashed lines are linear extrapolations of property values to coincide with "clean air" levels.

Total annual damage, or the decrease in real property income from pollution, is obtained by multiplying total capitalized damage by a discount rate reflecting the average return on capital:

TOTAL ANNUAL DAMAGE = (Discount Rate) x (DAMAGE)

Thus, the total capitalized pollution damage depends on: the choice of a marginal capitalized sulfation damage coefficient; the desired background sulfation rate; the annual arithmetic mean sulfation rate for the metropolitan area; the number of housing units over which the aggregation occurs; and, the discount rate.

In this report the following choices were made:

1. The studies reviewed here, taken together, show that the magnitude of the marginal capitalized sulfation damage for residential structures, for 0.1 mg/SO_3/100 cm^2-day, probably lies in the range of \$100 to \$600. For purposes of this report a range of damages will be estimated using extreme marginal capitalized sulfation damage coefficients of \$200 to \$500.
2. Selection of the desired background level at 0.1 mg/SO_3/100 cm^2-day was guided by the annual sulfation averages in selected suburban and rural regions.[67]
3. Annual arithemetic mean sulfation rates were established for all metropolitan areas either by: (a) using sulfation data on annual arithmetic means from the Interstate Surveillance Project;[68]

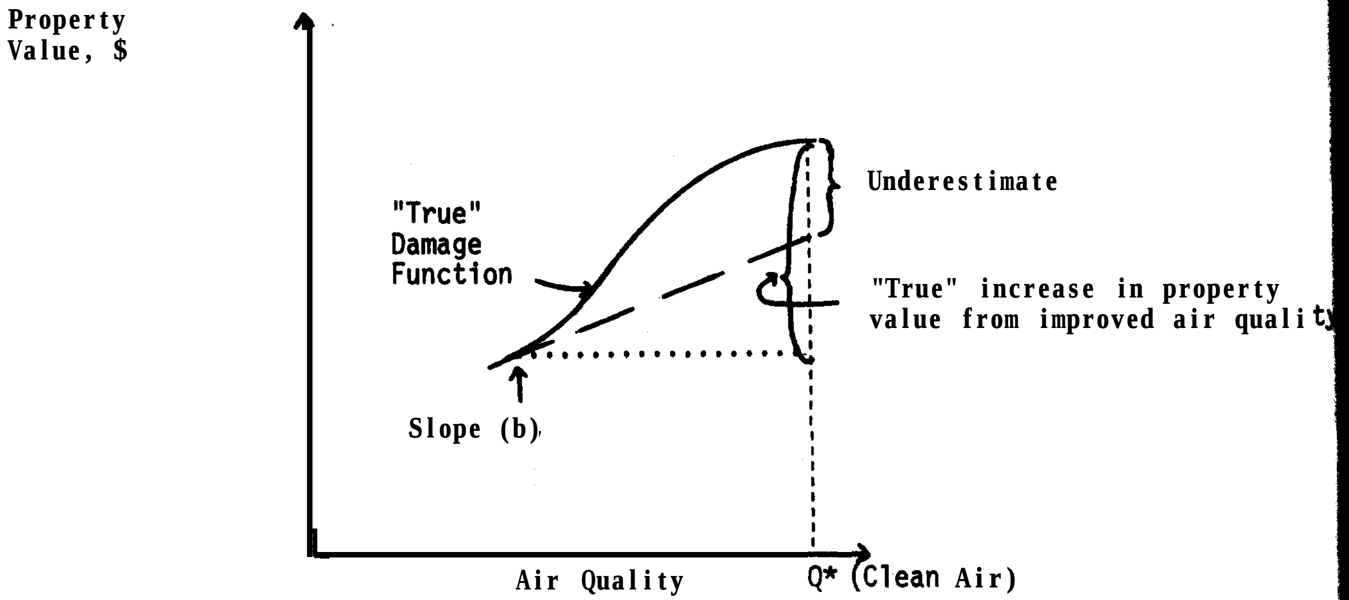

Figure 3. Underestimation of Property Value Losses

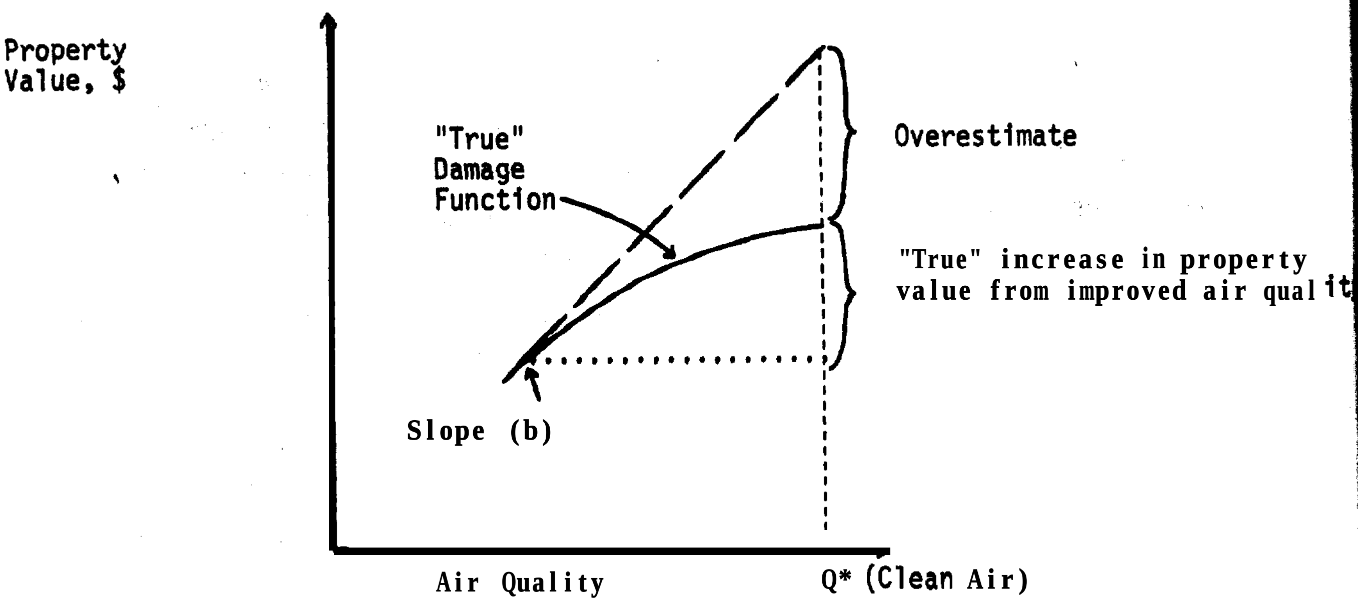

Figure 4. Overestimation of Property Value Losses

(b) using available sulfation data from EPA's SAROAD data bank and averaging monthly data; or (c) estimation for those metropolitan areas for which sulfation data were lacking, based on a regression of annual sulfur oxides (SO,) emission data on sulfation annual averages.

4. All estimates were calculated for the number of year-round housing units in each metropolitan area as given for 1970.[69]

5. As an approximation to an average return on all real property wealth in the economy, a 10% discount rate was uniformly used in all calculations.

As a result of the calculations described above, and assuming a range of marginal capitalized damage coefficients of \$200 to \$500 for each reduction in 0.1 mg/SO_3/100 cm^2-day, the national annual estimate for 1970 of air pollution damages measured via the property value differential method comes to \$3.4 to \$8.4 billion. A best approximation would probably be a middle estimate for a MPV of \$350, or a total damage of \$5.9 billion. 16.86 million households?

In conclusion, this estimate: (1) spans all housing units within all metropolitan areas; (2) assumes that pollution changes are spread evenly over all census tracts; (3) assumes that there is a negative relationship between sulfation and MPV; and (4) indicates the approximate amount that residents of American cities would demand, under emitter liability, to forego asserting their rights to have pollution abated so that arithmetic mean sulfation rates in all SMSA's would be 0.1 mg/SO_3/100 cm^2-day or lower.

As argued earlier (see Section III), it is believed that the costs associated with aesthetic effects as well as soiling-caused cleaning and maintenance expenditures are capitalized in this estimator. These costs reflect the tangible, experiential "disamenities" associated with air pollution. Here, the \$5.9 billion is used as an estimate of the damages to aesthetic properties and soiling, although it is recognized that other effects may be included in this

SECTION V

ASSESSMENT OF AIR POLLUTION DAMAGE TO HUMAN HEALTH

OVERVIEW OF THE PROBLEM

It is common to see references that cite health effects separate from the economic effects of air pollution. One inference can be drawn from this division: the effects of air pollution on health transcend economic values. While in fact there is a value, it is not easily measured. The separation may have been influenced largely by the absence of cost estimates for health relative to other types of damages.

What we are interested in here is how air pollution affects: illness and death rates, including partial disability; absence from work and school; and general expenditures on health protection and care. For example, we would like to know how many days of good health or work would be gained by a specific reduction in pollution. The obvious difficulty is: isolating the subtle, marginal effect of pollution on the complex human organism.

If health is defined as the general state of well-being, it might be convenient to think of a five-stage human response spectrum of increasing severity at a given level of air pollution (see Figure 5). While a significant percent of a population might be exposed to air pollution , only a smaller portion will be adversely affected, and then still a smaller fraction affected to the degree of death. The dashed line through the middle of the response spectrum in Figure 5 indicates that below this line, the health response is probably not economically significant. Above this dashed line, the response is expected to be of economic significance.

As indicated by the dotted line in Figure 5, the distinction between "psychic" and "normal" morbidity costs is unclear. While it is believed that such psychic costs do exist, they are probably only partially measured by "normal" morbidity indicators such as work-loss days, doctor visits, etc. Thus, any quantification of health costs that considers only morbidity and mortality costs will underestimate total health costs.. While recognizing that these

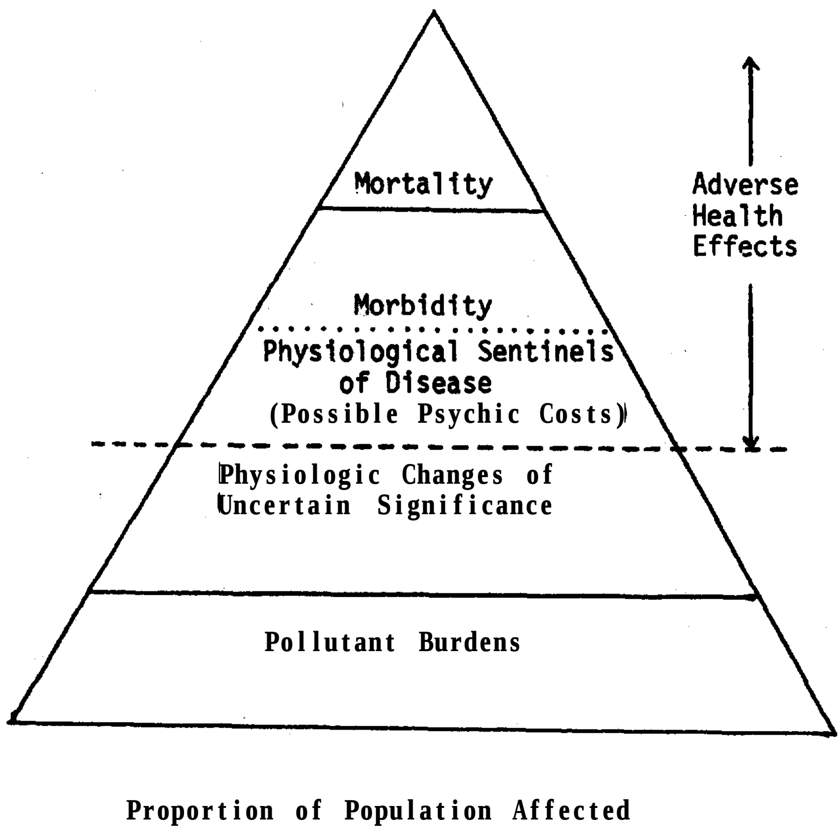

Figure 5. Human Response to Pollutant Exposure[a]

[a]Adapted from: C.M. Shy and J.F. Finklea, Air Pollution Affects Community Health. Environ. Sci. and Technol. 17 (3):205, March 1973.

subtle psychic costs are important, because of data limitations in this area, the analysis here will be restricted to the areas of morbidity and mortality.

Investigations focusing on the impact of air pollution on mortality rates, and on morbidity rates, represent two distinct areas of research. Death is often the result of a large number of unrelated causes. For example, a general "urban factor" has been identified as a causal agent in explaining mortality rates.[70] People in cities tend to lead more tense and less healthy lives; they smoke more, tend to be more overweight, and get less exercise. Somehow, the effects of air pollution must be separated from other causes explaining this "urban factor".

Lave lists and discusses the following factors that might affect mortality: (a) physiological characteristics which include age, sex, race, and genetic factors; (b) socioeconomic characteristics which include income, occupational mix, and fuels used for home heating; (c) environmental factors that include air pollution, radiation, and climatological factors; and (d) personal factors that include smoking habits, habits of exercise, medical care received, and general nutrition.[71] As Lave says almost in despair, "It is virtually impossible to account for all possible factors that might be the 'real' causes of ill health."[72]

INDIVIDUAL STUDIES

Even given the empirical problems, several notable attempts have been made to quantify the health costs attributable to air pollution. It appears that until 1970, Ridker (1967) had made the only significant published attempt to estimate the health costs due to air pollution. Since then, Riggan (1970) has estimated the health costs associated with automotive emissions. And, a study underway in the Environmental Protection Agency is attempting to estimate morbidity costs associated with a pollution composite of sulphur dioxide, total suspended particulates, and suspended sulfates. Finally, estimates of mortality costs associated with air pollution have been developed by Lave and Seskin (1970).

The studies by Ridker, Riggan, and the EPA follow the damage factor method where: (a) an estimate is made of the value of total health losses; (b) a proportionality factor is determined for the share of this value attributable to air pollution; and (c) the product of total health losses times this factor yields the value of health losses associated with air pollution.

In all three studies, the proportion of health losses associated with air pollution is determined assumed? to be a constant. Thus, the cost-of-pollution function for health may be taken to be linear with a negative slope. This assumption should be interpreted as an approximation over a limited range of a much more complex function. By assuming that a marginal improvement in health has a constant price over the estimated range of the damage function, the linear damage function gives rise to a linear benefit function.

Ridker - Morbidity and Mortality, Respiratory Diseases

The earliest known published attempt at estimating health costs resulting from air pollution is that of Ridker (1967). For the year 1958, he estimated the total national cost of morbidity and mortality for diseases associated with the respiratory system. The diseases considered were cancer of the respiratory system, chronic and acute bronchitis, pneumonia, emphysema, asthma, and the common cold. These diseases were chosen on the basis of crude empirical determinations and on *a priori* knowledge.

The cost estimates for each disease included the costs of premature death and burial, treatment costs, and costs associated with absenteeism. The costs of dying earlier than expected were estimated by the 1958 present value of lost future earnings. To put earnings on an annual basis, discount rates of 5 and 10 percent were applied to expected lifetime earnings, assuming full labor force participation. Costs of premature burial represented the difference between the present costs of burial and the present value of future expected burial costs discounted at rates of 5 and 10 percent. Treatment costs were estimated for each disease using per capita expenditures of drug manufacturers' shipments. Absenteeism costs were the product of days lost for each disease and the average annual earnings of those suffering from that disease. Summing the costs for 1958 (using a discount rate of 5 percent) yielded a total economic cost of these diseases of $1.99 billion. Table 5 presents Ridker's results.

Table 5. COSTS OF DISEASES ASSOCIATED WITH AIR POLLUTION

Type of cost	Costs[a] associated with selected diseases, $ million							
	Cancer of the respiratory system	Chronic bronchitis	Acute bronchitis	Common cold	Pneumonia	Emphysema	Asthma	Total
Premature death	518	18.0	6.0	na[b]	329	62	59	992.0
Premature burial	15	0.7	0.2	na	13	2	2	32.9
Treatment	35	89.0	na	200	73	na	138	535.0
Absenteeism	112	52.0	na	131	75	na	60	430.0
Total	680	159.7	6.2	331	490	64	259	1,989.9

[a]Using a discount rate of 5 percent.

[b]Not available.

Source: Ronald G. Ridker, Economic Costs of Air Pollution, New York: Frederick A. Praeger, 1967.

Ridker estimates that 18 to 20% of the approximate cost of $2 billion in national health costs for respiratory diseases are due to air pollution. His proportionality factors of 0.18 and 0.20 represent the proportion of health losses attributable to air pollution. These coefficients are taken from two studies relating, in one case respiratory mortality rates and, in the other, lung cancer mortality rates, to urban and rural areas. The coefficients are corrected for age, sex, race, smoking habits, and the proportion of U.S. population which is urban. Thus, the damage to health from air pollution in 1958 was estimated to be about $.4 billion.

Ridker considers the estimate to be quite conservative. For one thing, he recognizes the absence of avoidance costs representing the moving costs and possibly reduced earnings of those who migrate to areas of lower pollution because of their health. He did not impute the full value of housewife services lost due to death or illness related to air pollution. Nor was any attempt made to include any psychic costs associated with death or illness. Data limitations prevented estimates of full costs for some of the diseases considered and also prevented the consideration of certain diseases.

Full recognition is given to the inability to relate damages to specific types of pollution, thus preventing the construction of individual damage functions.

Riggan - Human Health and Motor Vehicle Pollution

Where the Ridker study will allow for estimation of the economic benefits to be derived from the abatement of air pollution, Riggan (1970) takes a more limited view. Riggan's study was not designed to generate national estimates of total health costs, but rather to investigate the economic costs of motor vehicle pollution on human health and the resulting losses to the Federal Government. In using the same general method as Ridker, Riggan estimates the value of income taxes that would have been paid to the Federal Government by people who died prematurely from automotive and related pollution. His total was $1.9 billion for 1970. He estimates the value of social security payments to workers disabled by automotive pollution to be $189.4 million. Riggan also'estimates a value of $97.1 million in lost productivity by

Federal workers in Washington, D.C., due to oxidant-causing eye irritation. His total dollar health cost attributed to motor vehicle pollution is estimated at $2.2 billion.

The study by Riggan is fraught with empirical problems, and it lacks a sound theoretic rationale. The methods used to derive the pollution coefficients that are applied to the total disease categories, are not clear. With respect to the theoretical problems, neither is it clear what a "cost to the Federal Government" really means. It can be argued that the author should have included estimates of the social security disability payments that the Government "saved" because of premature death. This inclusion might have forced the net cost down to the break-even point where the Federal Government neither lost nor gained because of pollution from automobiles and other related pollution. Therefore, the results from this study are not-used in this report to generate a national damage estimate for health.

Jaksch - Morbidity and Air Pollution in Portland, Oregon

Jaksch's (1972) study in Portland, Oregon, is a good example of a thorough morbidity-air pollution study that presents an economic-theoretic rationale for estimating health costs of air pollution. Using multivariate regression techniques, Jaksch attempted to isolate the effect of air pollution on the consumption of medical services by enrollees in the Kaiser pre-paid health plan. His supposition was that air pollution (suspended particulates in this case) can aggravate a state of health resulting in increased consumption of outpatient medical services, and in an increase of the number of contacts with the medical system, for certain respiratory, cardiovascular, and other diseases aggravated by air pollution. By considering a host of explanatory variables--for pollution exposure, personal attributes, socioeconomic-demographic characteristics, and meteorological-parameters, Jaksch was able to isolate suspended particulates as having some effect on the consumption of outpatient medical services used to treat diseases.

EPA - Morbidity, Selected Respiratory Diseases

In a study[73] being performed within the Environmental Protection Agency, research findings from the Community Health and Environmental Surveillance System (CHESS) Program[74] are being evaluated to determine the cost of selected adverse health effects associated with the pollution composite, sulfur dioxide-total suspended particulates-suspended sulfates. The following adverse health effects, which are associated with exposures to these air pollutants, are included in this study: acute lower respiratory disease and chronic respiratory disease.

The methodology employed in this EPA health study involved four steps. First, the impact of these air pollutants on disease rates was determined by statistical analyses of data collected from a number of CHESS communities offering different pollutant gradients. These communities were specifically selected to control for major co-determinats that might affect disease rates. Second, results of the association between these air pollutants and ill health-were extrapolated to other Standard Metropolitan Statistical Areas on the basis of relative pollution gradients. Third, the population affected was estimated by using disease rates provided by the National Center for Health Statistics, DHEW. Fourth, average per-case-costs were then applied to rough estimates of the affected population to determine the gross disease-specific costs. The following costs are being evaluated: (1) the direct medical expenditures for doctor visits, medicine, etc.; (2) work loss days; (3) housewife bed disability days; and (4) school loss days.

The objective of the EPA health study is to estimate the benefits of reducing in one case sulfur dioxide and particulates to levels of the primary air quality standards, and in the case of sulfates, to an assumed annual average standard of 6-8 μg/m3. There are obvious pitfalls associated with translating risk factors, severity-of-disease rates and average per-case-costs of selected diseases into economic estimates, Yet, such information on health costs should improve our understanding of the potential health benefits to be realized by abating such air pollution.

Lave and Seskin - Mortality

Lave and Seskin (1970) expanded the scope of diseases covered by Ridker (1967). In particular they added air pollution damages to health in the forms of heart disease and cancers of the stomach, esophagus, and bladder. In the case of bronchitis and lung cancer, they consider the evidence relating air pollution and health to be very reliable. Although evidence relating air pollution to heart disease and non-respiratory cancers is not so reliable, they believe that a consideration of all factors suggests causality.

Approximately half the lost income and current medical expenses associated with morbidity and mortality from bronchitis are ascribed to air pollution. The proportionality factor for lung cancer is estimated to be 25%. In the other categories, air pollution is responsible for an estimated 15% of the damages associated with non-respiratory lung cancers, 25% of all respiratory diseases, and 10% of cardiovascular diseases. These coefficients were estimated by regressions that were run on data from published epidemiological studies.

Based on these coefficients, the total annual cost of air pollution in increased human morbidity and mortality can be estimated to be $4.3 billion for 1963;[75] or inversely stated, a 50 percent reduction in air pollution would result in an annual savings of about $4.3 billion. These results are summarized in Table 6.

Table 6. HEALTH COST OF AIR POLLUTION, 1963

Disease Category	$ billion
Respiratory	1.9
Cancers	1.5
Cardiovascular	0.9
Total	4.3

Table 7. FACTORS AFFECTING THE MORTALITY RATE IN U.S. CITIES

$$MR_i = 19.607 + \underset{(2.53)}{.041}\ \text{mean}\ P_i + \underset{(3.18)}{.071}\ \text{min}\ S_i + \underset{(1.67)}{.001}\ P/M^2 + \underset{(5.81)}{.041}\%\ NW_i + \underset{(18.94)}{.687}\ \%\ 65_i + e_i$$

Sensitivity coefficients:	.53%	.37%	.07%	.57%	6.32%.

where:	MR_i	= the total mortality rate (per 10,000 people) in city i
	mean P_i	= the arithmetic mean of suspended particulate reading in city i
	min S_i	= the smallest biweekly sulfate reading in city-i
	P/M^2	= the population density in city i
	% NW	= the proportion of the population which is nonwhite in city i
	% 65_i	= the proportion of the population 65 and older in city i
	e_i	= an error term for variation in the mortality rate not explained by the equation

Notes: The figures in parentheses are the t statistics for a test that the estimated coefficient is not significantly different from zero (no effect).

The sensitivity,coefficients show the expected increase in the mortality rate estimated to come from-a 10% increase in each variable in turn.

The equation explains 82.7% of the variation in the mortality rate across 17 cities in 1960.

In their cross-section study of 117 cities, Lave and Seskin (1973) used multivariate regression techniques to explain variation in mortality rates as a function of air pollution, socioeconomic variables, and age. Their regression (Table 7) explains 83% of the total variation in mortality rates for those cities. The regression is a linear equation which predicts the mortality rate within a city on the basis of air pollution, population density, the proportion of non-whites in the population, and the proportion of the population age 65 and older. All coefficients in the regression are shown to be significant.

The "sensitivity coefficient" shows how much the mortality rate would be estimated to increase if one of the variables were to increase by 10%, i.e., if the mean level suspended particulate increased 10%, results show that the mortality rate would increase .53% and a 10% increase in both particulates and sulfur oxides would increase the mortality rate by .90%. Assuming the linear relationship between air pollution (as defined here) and mortality, a 50% decrease in air pollution is associated with a reduction in the mortality rate by 4.5%. Lave concludes that while the individual sensitivity coefficients cannot be argued as "true", their general magnitude cannot be doubted.[76]

For several reasons, Lave and Seskin consider their estimate to he conservative. They argue that for conceptual meaning, the willingness of an individual to pay for improved health or longevity, given a level of income and wealth, is the true measure of health costs due to air pollution.[77] To Lave and Seskin, the sum of income lost and current expenditures resulting from morbidity and mortality caused by air pollution is a gross underestimate of willingness-to-pay. Also, some health costs may have been overlooked, resulting in a more conservative estimate. Finally, the exclusion of some treatment costs results in the underestimation of true damages.

The regression survived a number of tests and manuevers designed to identify any spurious relationships. Air pollution was significant where expected, such as in explaining the mortality rates of the very young, the very old, and people dying of cardiovascular and respiratory diseases. Also, air pollution was not significant where expected, neither in explaining the mortality rates for young adults, nor for people dying from suicide.

NATIONAL ESTIMATE OF HEALTH LOSSES

It is believed that the findings of EPA's CHESS program on morbidity and Lave and Seskin's work on mortality provide an acceptable basis on which a gross damage estimate of the health costs of air pollution can be made. By applying the general methodology utilized in the EPA study to an analysis of the CHESS findings on the health effects of sulfur dioxide, suspended particulates, and suspended sulfates, rough measures of some economic health benefits of controlling these pollutants can be estimated. This crude methodology is outlined in Table 8.

In Table 8 the particular health effects are identified in the different reports from CHESS. Estimates of affected populations are based on: data on populations-at-risk taken from an internal EPA report; data on disease rates published by the National Center for Health Statistics; and, population data recorded in the Statistical Abstract of the U.S.-1972. The estimated change for each health effect is based on an interpretation of the data reported in the individual CHESS studies. Estimates of cost-per-health effect are based upon information taken from the Statistical Abstract of the U.S.-1972 and NCHS reports, tempered with best judgment. Results of this process yield rough estimates of the benefits to human health of controlling sulfur dioxide, suspended particulates, and suspended sulfates. The human morbidity costs for 1970 determined in this manner are estimated to range from roughly $.9 to $3.2 billion.

In extrapolating the Lave and Seskin results, if 1970 air pollution levels (total suspended particulates) were reduced by 26% (in order to reach the primary ambient air quality standard), the savings in morbidity and mortality costs would be $3.73 billion. This was determined here in the following manner: First, Lave and Seskin's regression of air pollution and mortality shows that a 26% reduction in air pollution in major urban areas would lower. the mortality rate by 2.33 percent.[78] Second, usinq cost figures developed by Rice,[79] the value for this percent reduction in mortality and morbidity in 1963 was $2.24 billion.[80] Third, extrapolating this value to 1970, the estimate becomes $3.73 billion.[81]

Table 8. ROUGH ESTIMATES OF SOME HEALTH BENEFITS THAT CAN BE REALIZED BY THE CONTROL OF SULFUR DIOXIDE, SUSPENDED SULFATES, AND SUSPENDED PARTICULATES

Health effect	Rough estimate of population affected,[a] million people	Estimated possible change	'Rough estimate of annual health benefits, $ million
Irritation symptoms arising from acute air pollution episodes	50	Symptoms 75-100% eliminated	Not known
Impairment of ventilatory function	50	Subtle improvement[c]	Not known
Symptom aggravation in the elderly	4	On the average 10-30% fewer would report a worsening of symptoms[d]	150-800[e]
Asthma attacks	4	On the average 10-50% fewer asthmatics might report an attack[f]	50-390[g]
Acute lower respiratory	50	Reduction in restricted activity days by 10-40% and physician visits by 20-50%[h]	400-1500[i]
Chronic bronchitis	6	Reduction in prevalence by 20-40%[j]	300-600[k]

(See attached notes)

NOTES ON TABLE 8

a. Populations-at-risk data are taken from: W.C. Nelson, et. al., Estimates of Populations-at-Risk, Environmental Protection Agency, Division of Health Effects Research, Research Triangle Park, N.C., In-House Technical Report, January 1972. Population data are taken from: Statistical Abstract of the United States - 1972 (93rd Edition), U.S. Bureau of the Census, Washington, D.C. Data on disease rates are taken from: Current Estimates from the Health Interview Survey, United States - 1970, U.S. DHEW, PHS, NCHS, Rockville, Md., Vital and Health Statistics, Series 10, No. 72, May 1972.

b. Source: C.J. Nelson, et. al. Family Surveys of Irritation Symptoms Durinq Acute Air Pollution Exposures: 1970 Summer and 1971 Spring Studies. JAPCA 23(2):81-86, February 1973.

c. Source: C.M. Shy, et. al Ventilatory Function in School Children: 1970-1971 Testing in New York Communitites; and C.M. Shy, et. al Ventilatory Function in School Children: 1967-1968 Testing in Cincinnati neighborhoods. Both studies are in: Health Consequences of Sulfur Oxides: A Report from CHESS, Environmental Protection Agency, Human Studies Laboratory, Research Triangle Park, N.C. (In press).

d. Source: H.E. Goldberg, et. al. Frequency and Severity of Cardiopulmonary Symptoms in Adult Panels: 1970-1971 New York Studies. In: Health Consequences of Sulfur Oxides: A Report from CHESS.

e. Determined by inflating the estimated health expense for a person with a chronic condition with a limitation in activity (Source: Personal Health Expenses Per Capita Annual Expenses, United States: July-December 1962. Vital and Health Statistics, Series 10, Number 27, February 1966, Table 9, p. 30) to 1970 on the basis of the medical care price index (Source: Statistical Abstract of the United States - 1972, Table 90, p. 65).

f. Source: J.F. Finklea, et. al., Aggravation of Asthma by Air Pollutants: 1971 Salt Lake Basin Studies; and J.F. Finklea, et. al., Aggravation of Asthma by Air Pollutants: 1970-197o New York Studies. Both studies are in: Health Consequences of Sulfur Oxides: A Report from CHESS.

g. Based on a best judgment estimate of $15 per asthmatic attack. This estimate might include the direct cost of medicine and other health services, as well as the cost associated with resultant restricted activity-days.

h. Source: W.C. Nelson, et. al., Frequency of Acute Respiratory Disease in Children: Retrospective Survey of Salt Lake Basin Communities, 1967-1970; J.F. Finklea, et. al., Frequency of Acute Lower Respiratory Disease in Children: et. al., Prospective Surveys of Acute Respiratory Disease in Volunteer Families:

1969-1970 Chicago Nursery School Study; and G.J. Love, et. al., Prospective Studies of Acute Respiratory Disease in Volunteer Families 1970-1971 New York Studies. All of these studies are in: Health Consequences of Sulfur Oxides: A Report from CHESS.

i. Based on the value of $11 for a restricted activity-day. This value is dermined by dividing the per capita income in the U.S. for 1970, by the number of days in the year. Data on restricted activity days for acute lower respiratory disease are taken from: Acute Conditions: Incidence and Associated Disability, United States - July 1969-June 1970. Vital and Health Statistics, Series 10, Number 77, Table 2, p. 12; the percentage of these restricted activity days that might be associated with populations within SMSA's are determined from Table 11, p. 21; and the number of physician visits is determined from Table 4 (p. 14) and Table 11 in 'much the same manner. These physician visits are then valued by dividing the per capita consumer expenditures for physician services (Source: Statistical Abstract of the'U.S. - 1972, Table 92, p. 66) by the physician visits per capita -(Statistical Abstract of the U.S. - 1972, Table 100, p. 69).

j. Source: D.E. House, et. al., Prevalence of Chronic Respiratory Disease Symptoms in Adults: 1970 Survey of Salt Lake Basin Communities; C.G. Hayes, et. al., Prevalence of Chronic Respiratory Disease Symptoms in Adults: 1970 Survey of Five Rocky Mountain Communities; J.F. Finklea, et. al., Prevalence of Chronic Respiratory Disease Symptoms in Military Recruits, 1969-1970; and, H.E. Goldberg, et. al., Prevalence of Chronic Respiratory Disease Symptoms in Adults: 1970 Survey of New York Communities. All of these studies are in: Health Consequences of Sulfur Oxides: A Report from CHESS.

k. Based on the inflation to 1970 of the annual expense to a person with a chronic condition with no limitation in activity on the basis of the medical care price index (Source: See Note e).

This amount of $3.73 billion includes direct health expenditures and the discounted present value of lost future earnings sue to morbidity and mortality. This estimate probably understates the true cost of death caused by air pollution because: (1) since people are valued according to their earnings, a person not earning wages is usually valued at zero; and (2) the willingness-to-pay for improved health normally exceeds the costs incurred for protection and care.[82]

It is possible that Lave and Seskin have stronger faith in the magnitude, sign, and statistical significance of their regression coefficients than what their analysis would seem to support. Their many statements about the causes of these "effects" may not be as justified as they seem to conclude. Some of the difficulties with their work include the use of aggregate correlations, inadequate exposure data, no personal covariate information such as smoking or occupational exposure, and mobility.[83] They are also faced with the obvious problem of regressing aggregated data collected for different reasons. Yet in fairness, despite the author's questionable data and extended discussion of their results, their estimate of health costs is believed to be reasonable.

While Lave and Seskin struggle with the multiple causation dilemma and generally ignore the multicollinearity problem, the CHESS design attempts to separate major co-determinants of disease, primarily through analysis of variance techniques. Multiple, repetitive health, personal covariate, meteorologic, and environmental pollutant exposure measurements were taken in CHESS on tens of thousands of individuals to estimate the relative effects of multiple pollutant exposures. Even though the results seem to be reasonable, several criticisms concerning the CHESS design have been levied. These criticisms relate to the bias in the samples and the argument that significant socio-economic covariates are not adequately accounted for.

From the extrapolated CHESS data and the Lave-Seskin study, it seems that a defensible estimate of health costs for 1970 can be made. The CHESS data extrapolated in this report estimates morbidity costs associated with selected respiratory diseases, Lave and Seskin's work estimates morbidity and mortality costs associated with the same respiratory diseases that the CHESS study considers, as well as many others. The Lave-Seskin estimate of morbidity costs is inferred from their mortality estimate. In contrast, the CHESS estimate for selected respiratory diseases is based upon direct analysis of morbidity rates and air pollution. Since the CHESS estimate would seem to be a more reliable estimate of those respiratory morbidity costs, it is desirable that this estimate rather than the Lave-Seskin estimate for those same diseases be included in the aggregate health cost estimate.

Thus, in order to make the two estimates additive, the component identified in the Lave-Seskin estimate as morbidity and direct expenditures for respiratory diseases, must be subtracted from the $3.73 billion. Such an operation results in a health estimate of $3.51 billion. Given that 73.5% of the total population in 1970 lived in urban areas, this further reduces the estimate of health costs to $2.58 billion.[84] If then, the variance about the mean is considered, a range of $0.7-4.4 billion can be generated for 1970. Adding this range of estimates to the range of $.9-3.2 billion generated by extrapolating the CHESS data, the range of gross estimates of health costs associated with air pollution for 1970 becomes $1.6-7.6 billion.

This gross health estimate represents the benefits that would be realized by reducing air pollution in major urban areas to the particulate primary standard of 75 $\mu g/m^3$, the sulfur dioxide primary standard of 80 $\mu g/m^3$, and the assumed sulfate standard of 6-8 $\mu g/m^3$. Given the lack of knowledge to the contrary, it is assumed that the estimates generated by the two studies are additive in the sense that they have been handled here. It can be concluded that the middle of the range, $4.6 billion, is the "best" estimate of the true costs adverse effects of air pollutants on human health and longevity.